Beam Induced Pressure Rise in Ring
~ Experiences in KEK B-Factory ~

Y.Suetsugu

KEKB Vacuum Group, KEK

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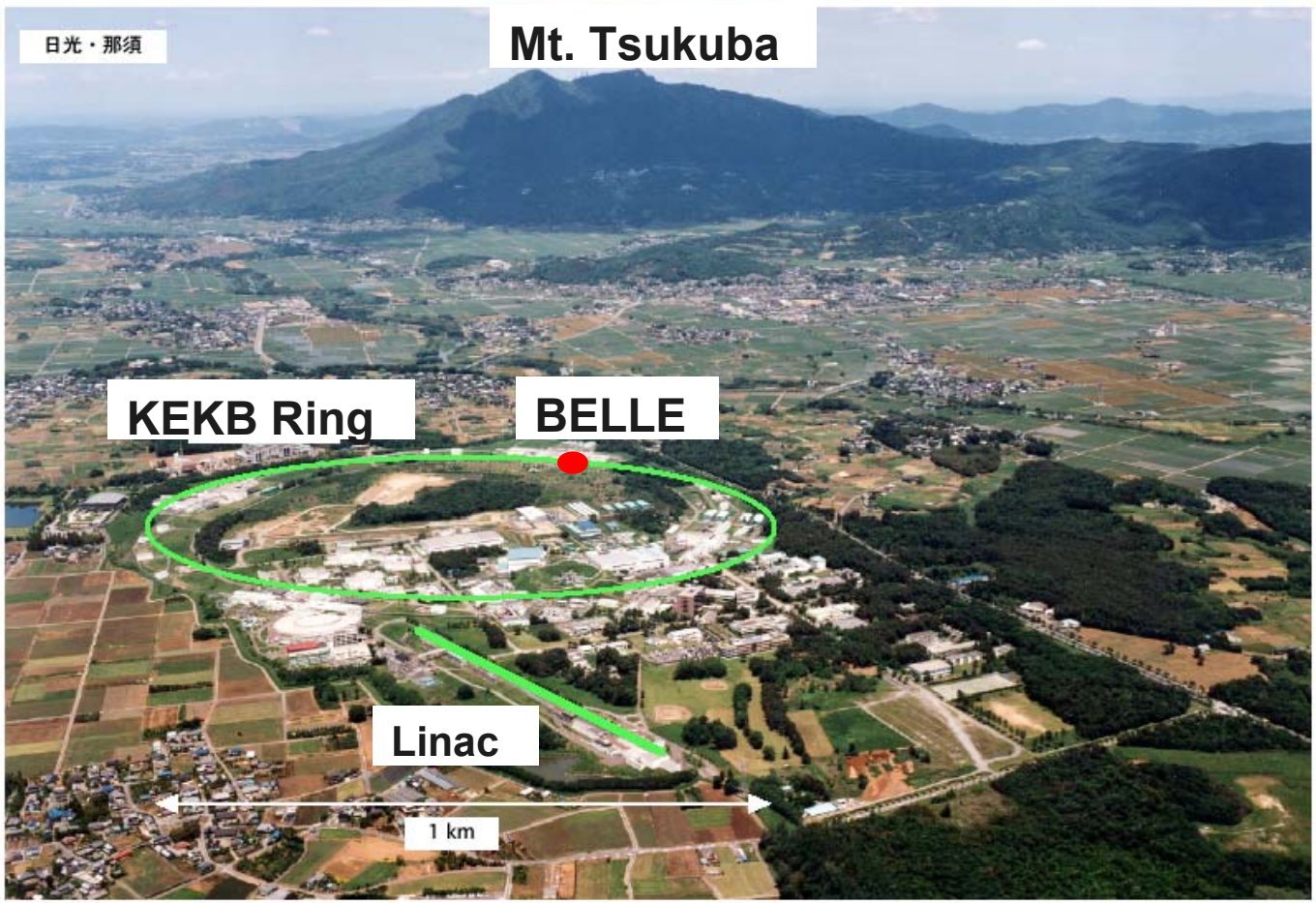
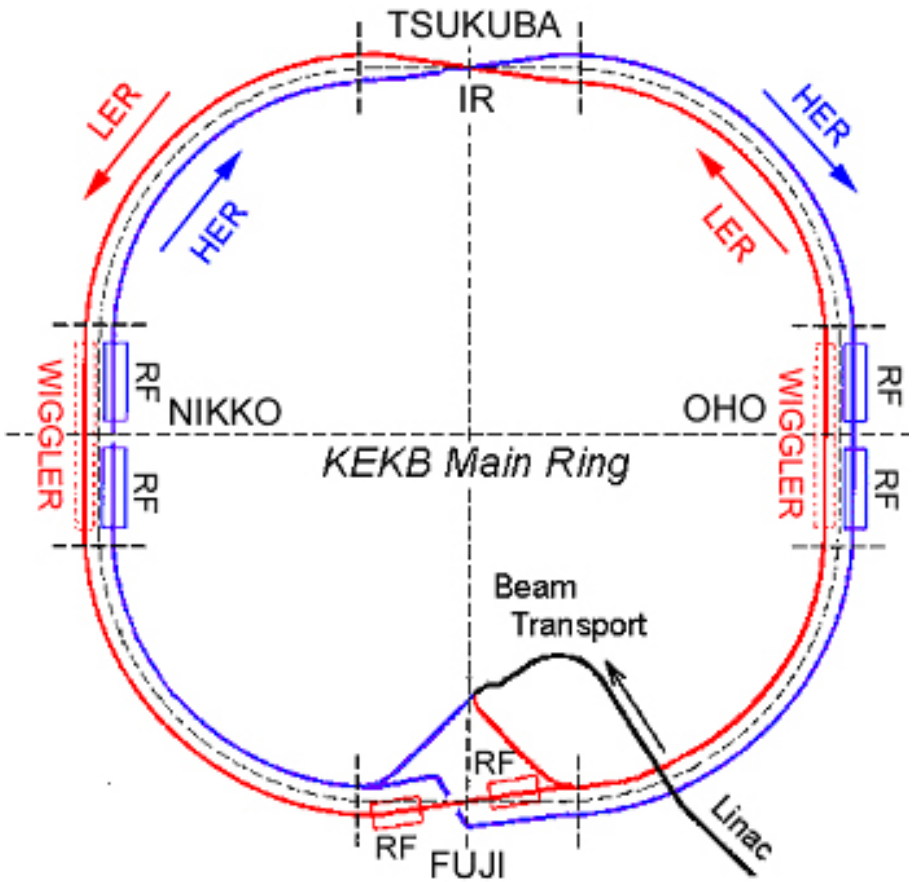
- KEK B-factory (KEKB): A dedicated accelerator to quest the CP-violation in the bottom-quark decay



1. Introduction_2

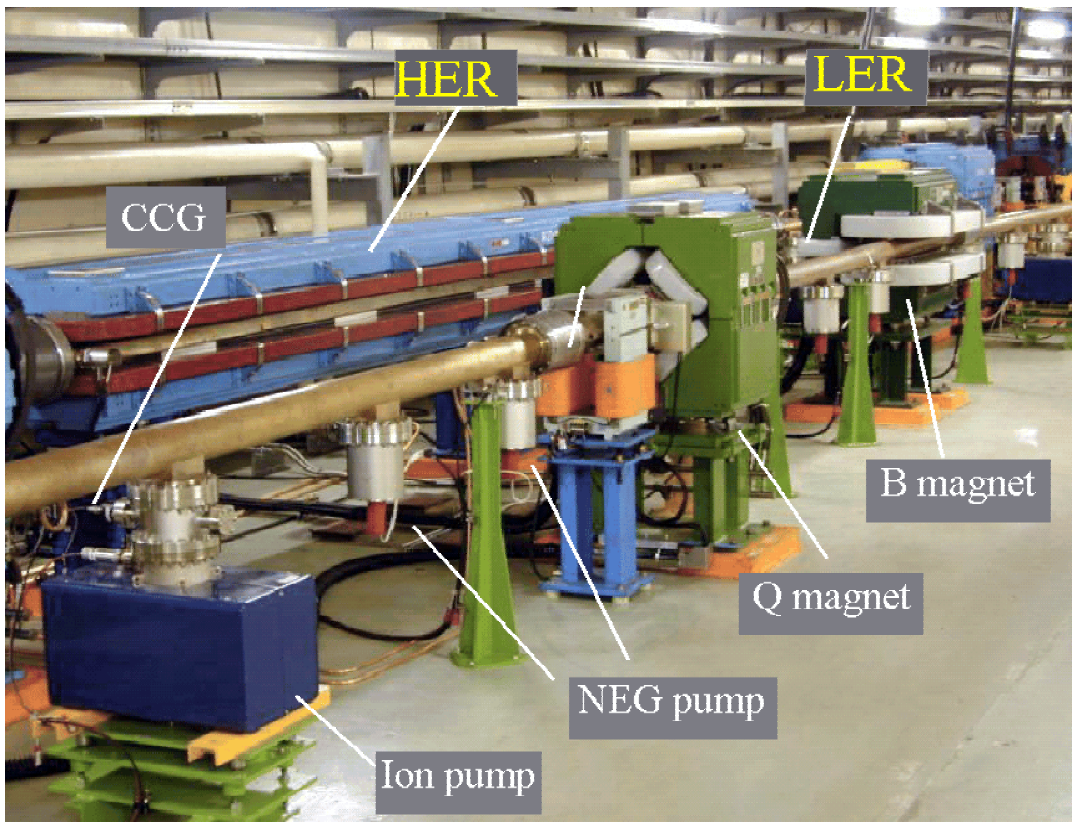
- KEK B-factory (KEKB): A dedicated accelerator to quest the CP-violation in the bottom-quark decay



- Asymmetric two ring collider
  - Electron ring (HER) : 8 GeV
  - Positron ring (LER) : 3.5 GeV
  - Circumference : 3016 m
- Design:
  - Beam current = 1.1 A x 2.6 A
  - Bunch length = 6 mm
  - Bunch number = 5000 (2ns)
  - Goal Luminosity = 1×10^{34} $cm^{-2}s^{-1}$

1. Introduction_3

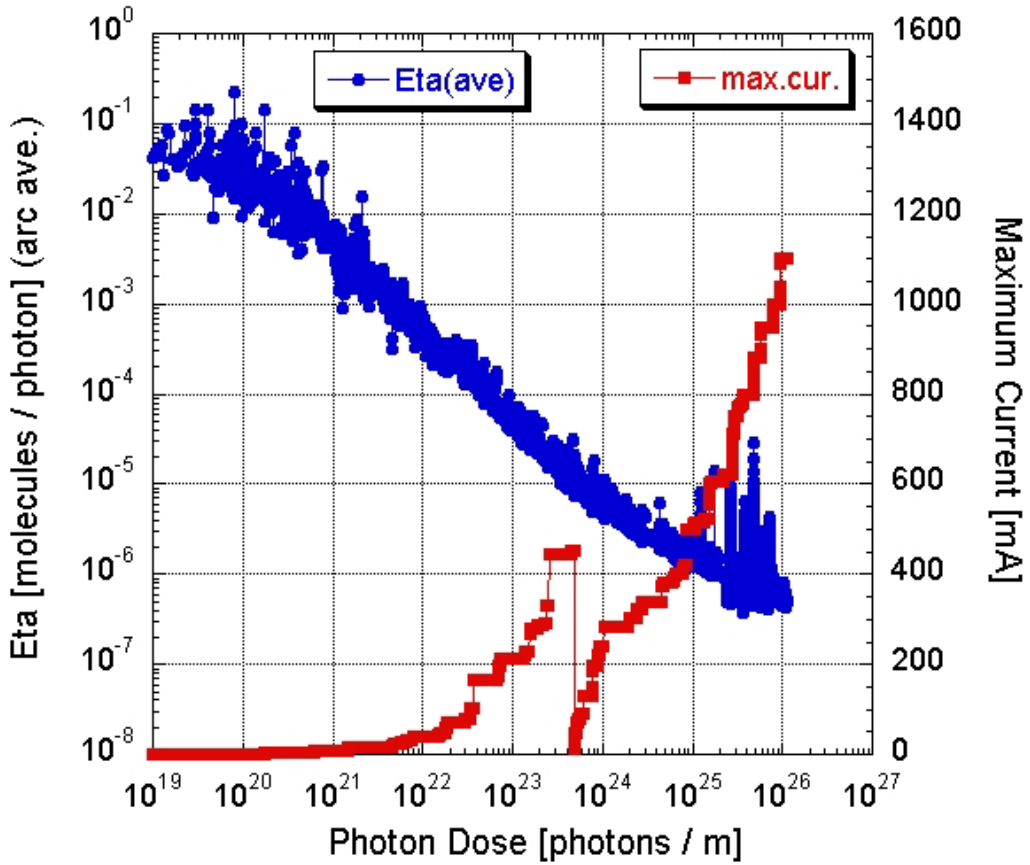
Vacuum System



- Material of duct :
  - Pure Copper (OFC)
  - Chemical Polishing
  - (No coating)
- Cross sections :
  - LER ϕ 94
  - HER 102x50 (Race track)
- Pumps :
  - NEG + IP
  - Oil Free Rough pumps
- Pumping speed :
  - $\leq 0.1\ m^3\ s^{-1}\ m^{-1}$ in ave.

1. Introduction_4

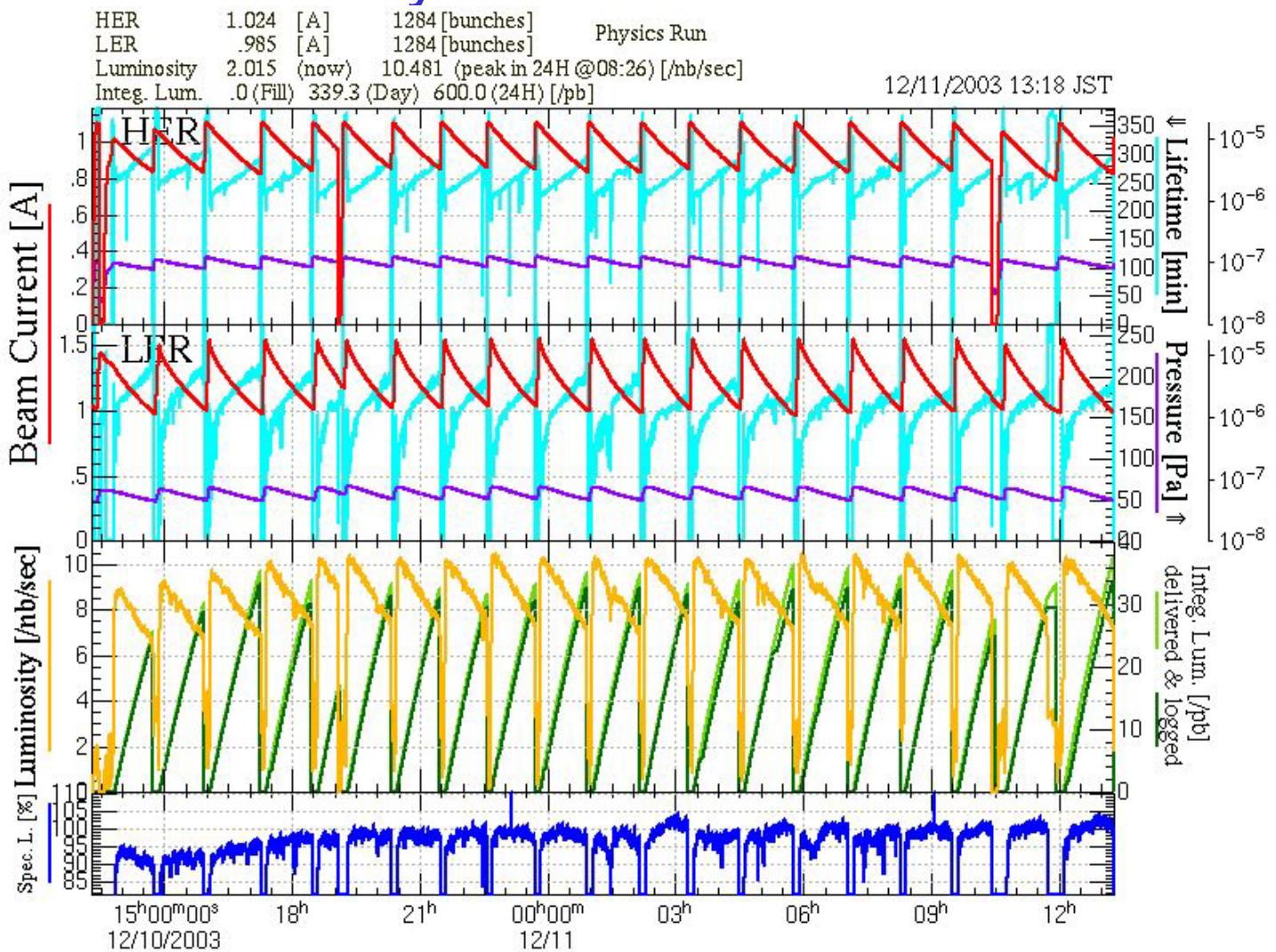
Vacuum Scrubbing (HER)



- Integrated beam current (beam dose) :
  ~ 1×10^{4} A Hours
- Integrated linear photon flux (photon dose):
  ~ 1×10^{26} photons/m
- $\Delta P/\Delta I$: 2×10^{-7} Pa/A
- η : 5×10^{-7} mole./photon
- Max. Beam current :1.1 A
- Almost same with LER

1. Introduction_5

- Yesterday's run of KEKB



Beam Current
1.1A x 1.5 A
(1284 bunches
≈ about 8ns)

Bunch Length
6 mm

Lifetime
250, 150 min

Ave. Pressure
~10^{-7} Pa

Luminosity(Peak)
~$1 \times 10^{34} cm^{-2}/s$

1. Introduction_6

- KEKB Vacuum System:

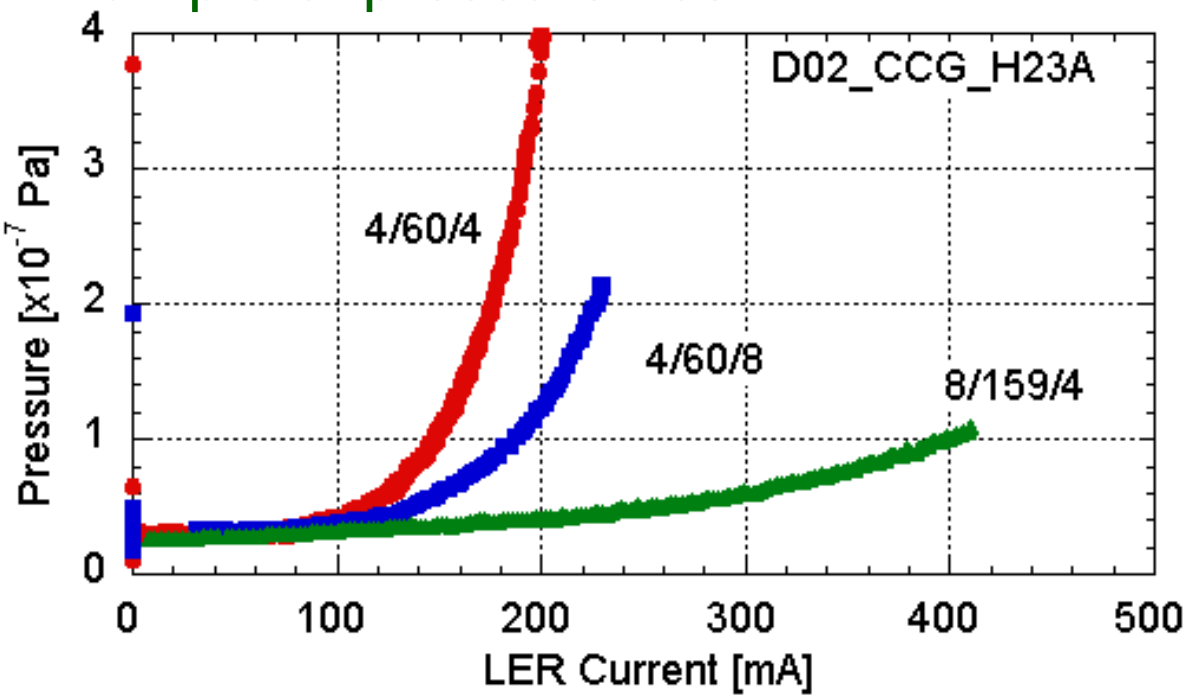
  Working almost well at present

- Various problems have occurred so far.
  - On abnormal pressure rise due to other than SR:
    - Due to electrons (in positron ring)
    - Due to injection beam ? (electron and positron rings, not understood yet)
    - Due to heating by HOM (positron ring, but possible in electron ring too)
- Here these phenomena and measures to them are reviewed briefly.

2.1 Pressure rise due to electrons_1

- Non-linear pressure rise against the beam current has been observed at almost every place in positron ring.

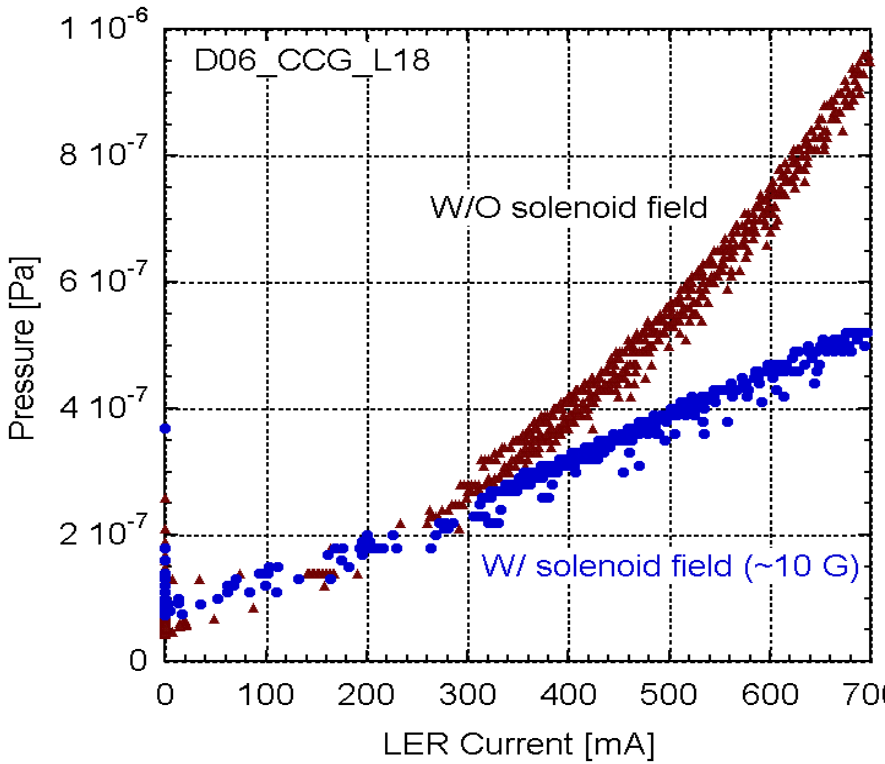
Example of pressure rise



The symbol of 4/60/8, for an example, means that the beam consists of 4 trains of 60 bunches filled with every 8 RF buckets spacing (16 ns).

2.1 Pressure rise due to electrons_2

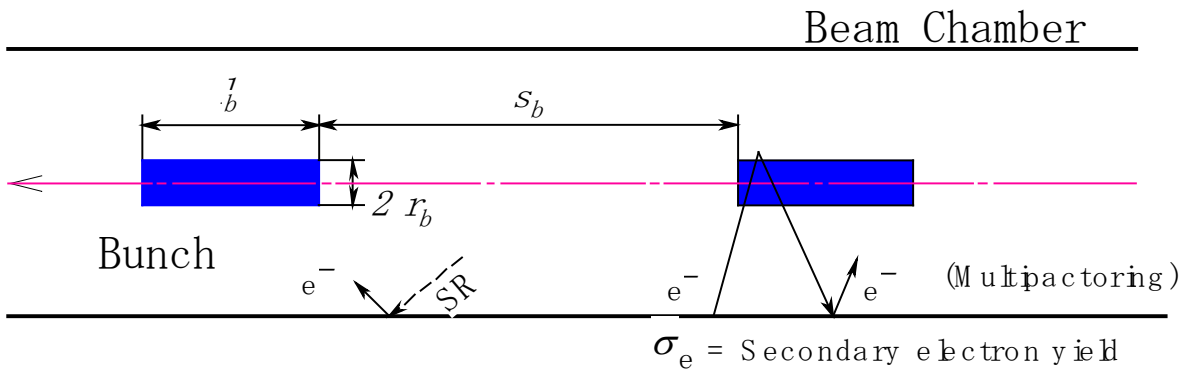
- Characteristics
  - Observed in only positron ring (almost everywhere)
  - Depends on bunch fill pattern
  - Pressure increases non-linearly with beam current
  - Affected by external magnetic field. Several gausses of magnetic filed suppress the phenomena.

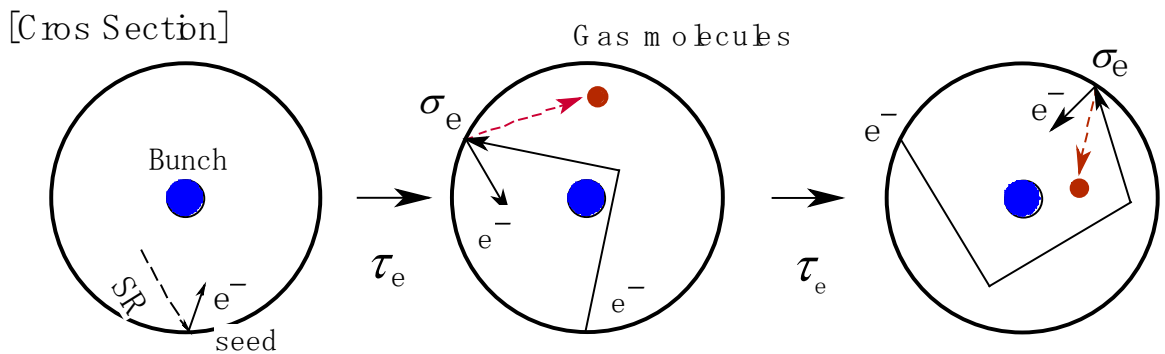


Gas desorption due to the electron multipactoring.

2.1 Pressure rise due to electrons_3

- Model





Photoelectron emission
→ Acceleration by e^+ bunches
→ Bombardment to wall with a high energy
→ Secondary electron emission

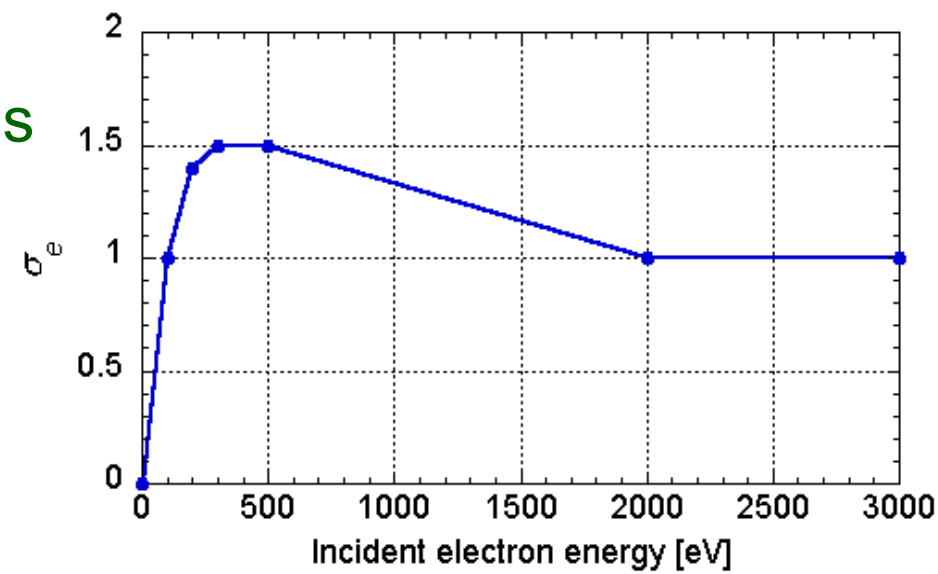
A simple (primitive)2D simulation was performed.

Already talked in “Two Stream WS (2001)”

Based idea was given by O.Gröbner (CERN,1977)

2.1 Pressure rise due to electrons_4

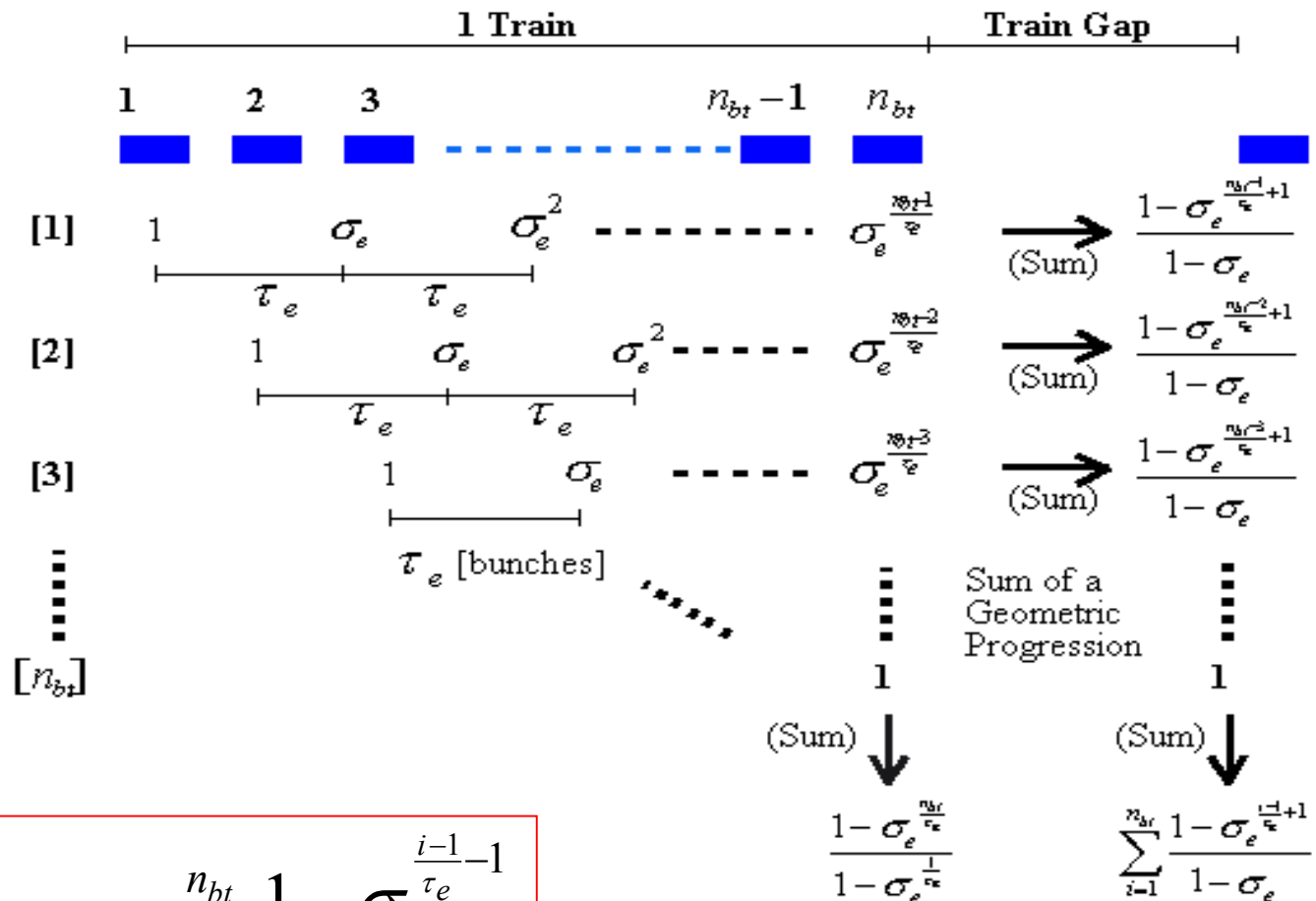
- In the simulation, average life time of electrons(τ_e) and average yield (σ_e) are calculated by tracking lots of electrons
- Assumptions:
  - Initial energy of emitted electrons is in the range 2 ~ 8 eV
  - No space charge effect
  - Angular distribution of the emitted electrons follows the cosine law
  - Electrons and gas molecules inside the chamber is completely cleared during a train gap
  - Rigid bunch (cylinder)
  - Secondary electron yield :



2.1 Pressure rise due to electrons_5

- Estimation of pressure

P
∞
Number of electrons generated in a train



$$P \propto I_{bunch} \times N_{train} \times \sum_{i=1}^{n_{bt}} \frac{1-\sigma_e^{\frac{i-1}{\tau_e}-1}}{1-\sigma_e}$$

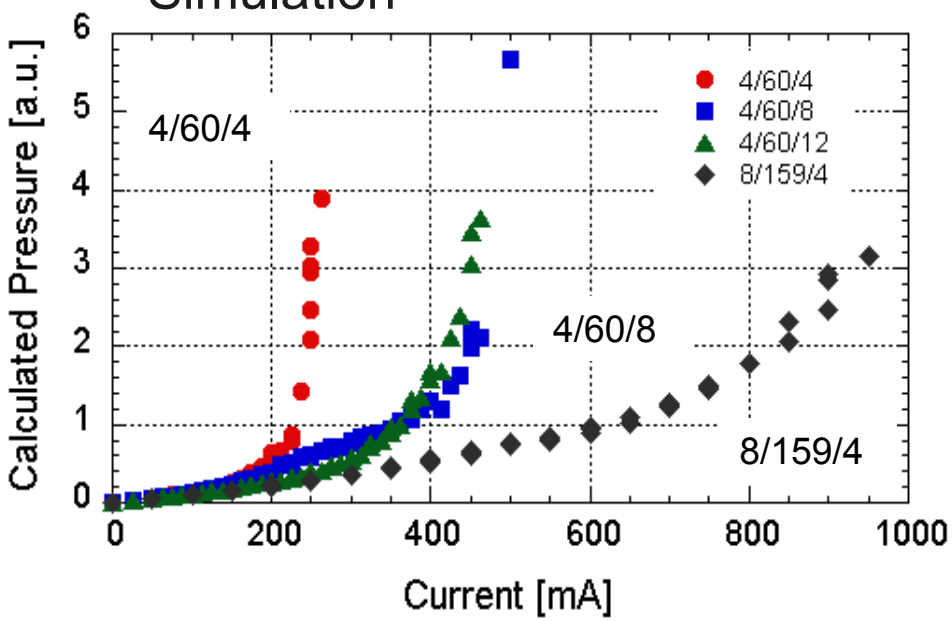
EID is constant

IF σ_e << 0 -> photo-desorption

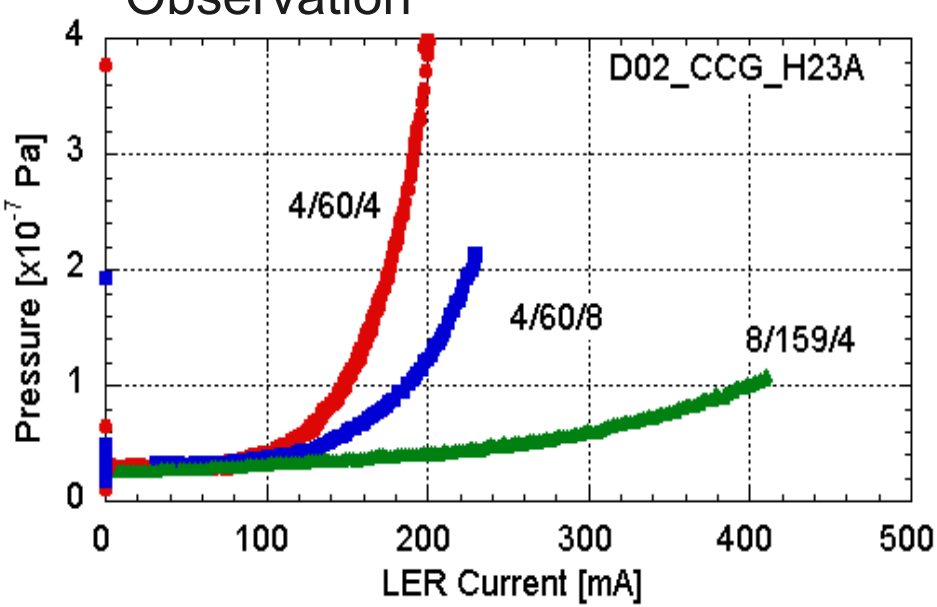
2.1 Pressure rise due to electrons_6

- Bunch Fill Pattern Dependence

Simulation



Observation

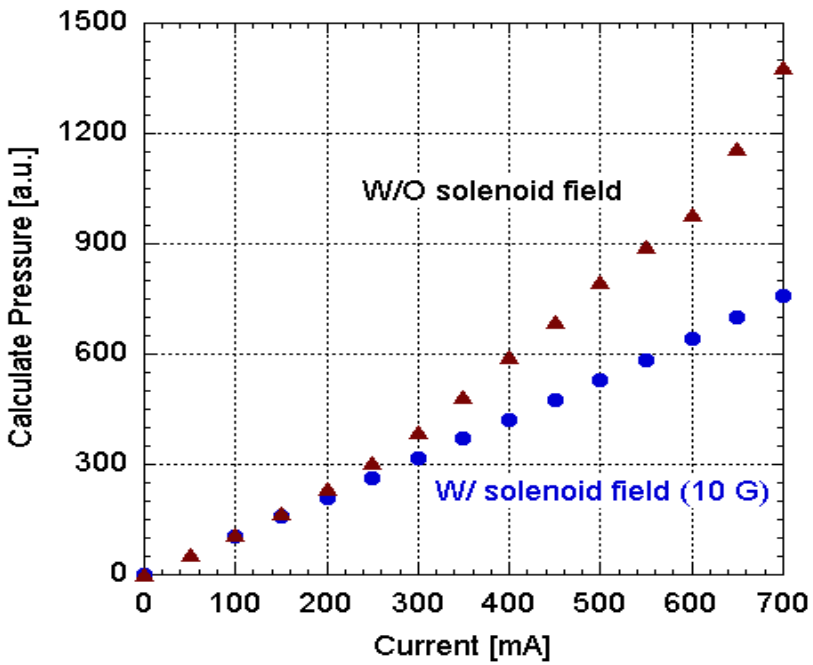


- Result of simulation is similar to observation although the corresponding current is somewhat different.

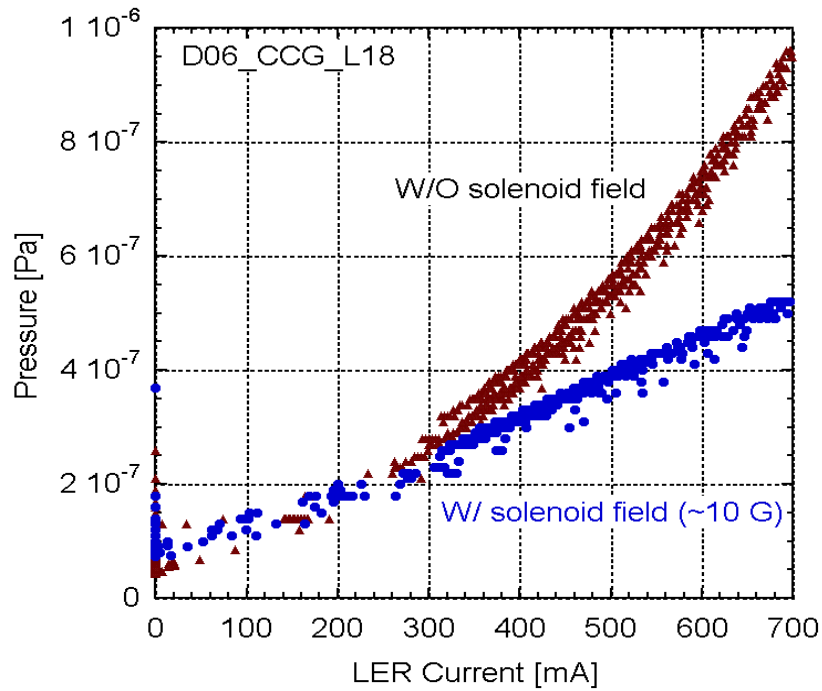
2.1 Pressure rise due to electrons_7

- Magnetic Field Dependence

Simulation



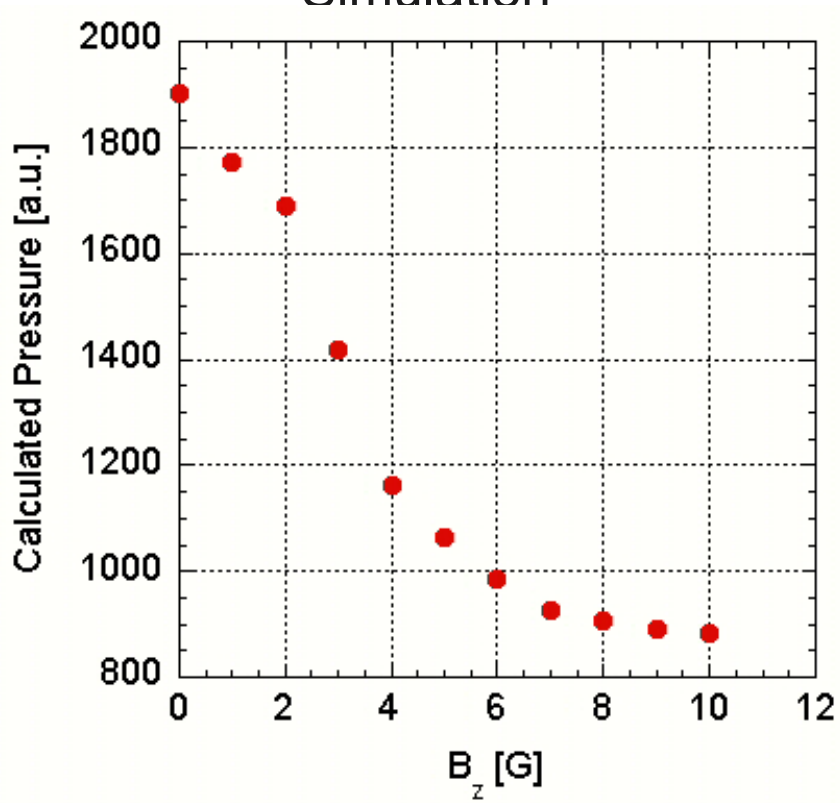
Observation



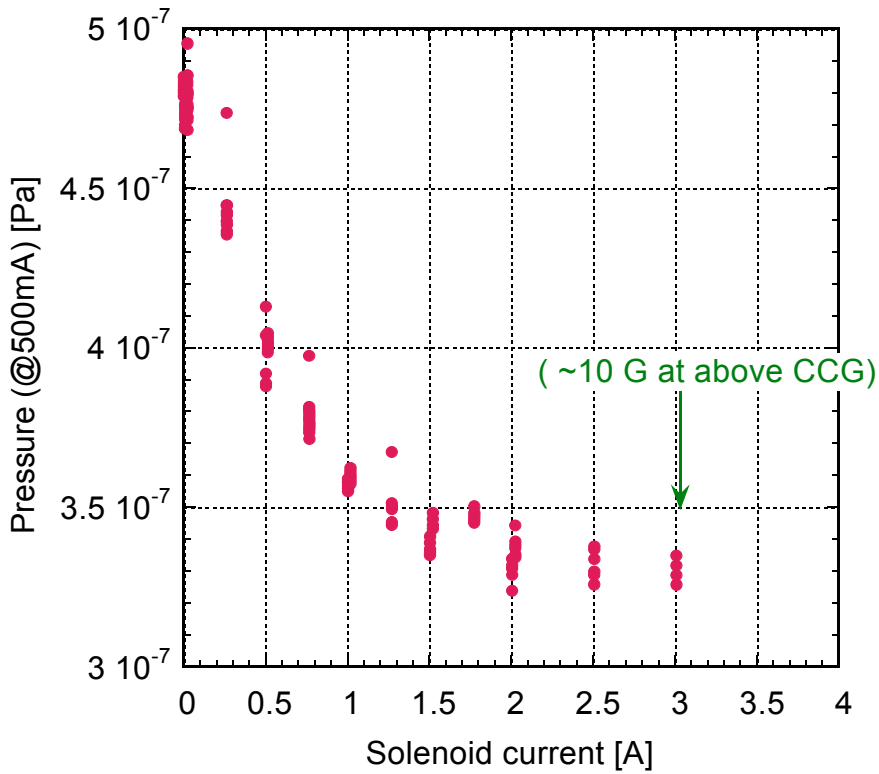
2.1 Pressure rise due to electrons_8

- Magnetic Field Dependence: P at 500 mA

Simulation



Observation

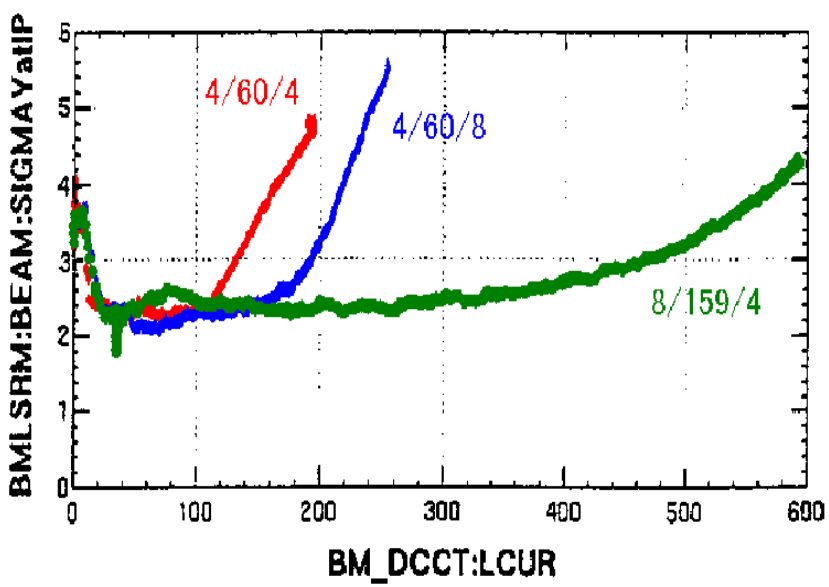


- Simulation assuming multipactoring of electrons explains well the non-linear pressure rise qualitatively

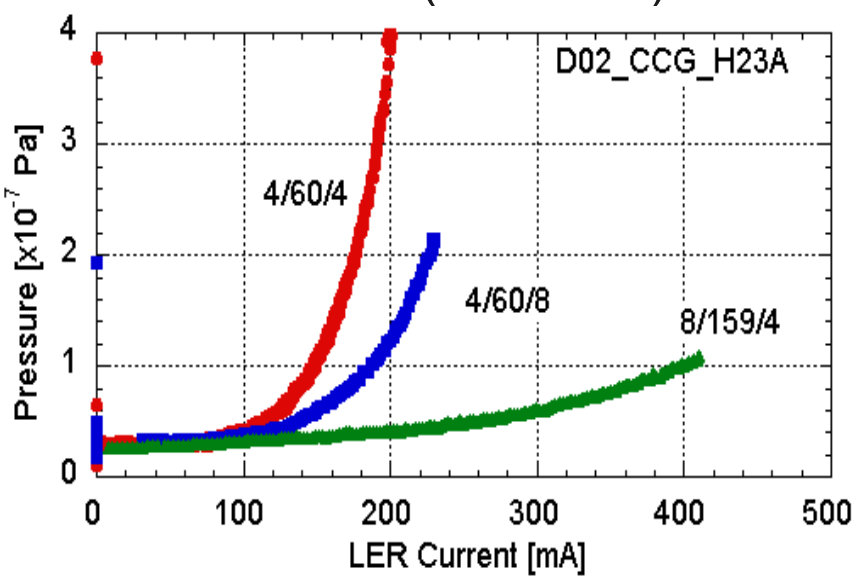
2.1 Pressure rise due to electrons_9

- Relation to beam size blow up (ECI)
  - Blow up ⬅ Head-tail instability (single beam)
  - Behaviors are very similar to those of pressures
  - Indicates a deep relation between non-linear pressure rise and ECI based on electron multipactoring

Observation (Beam size)



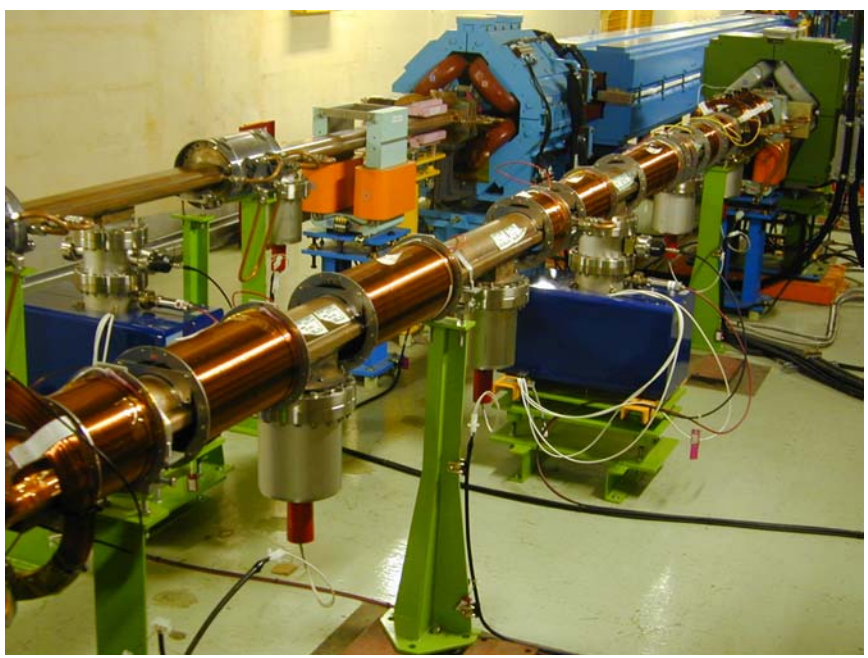
Observation (Pressure)

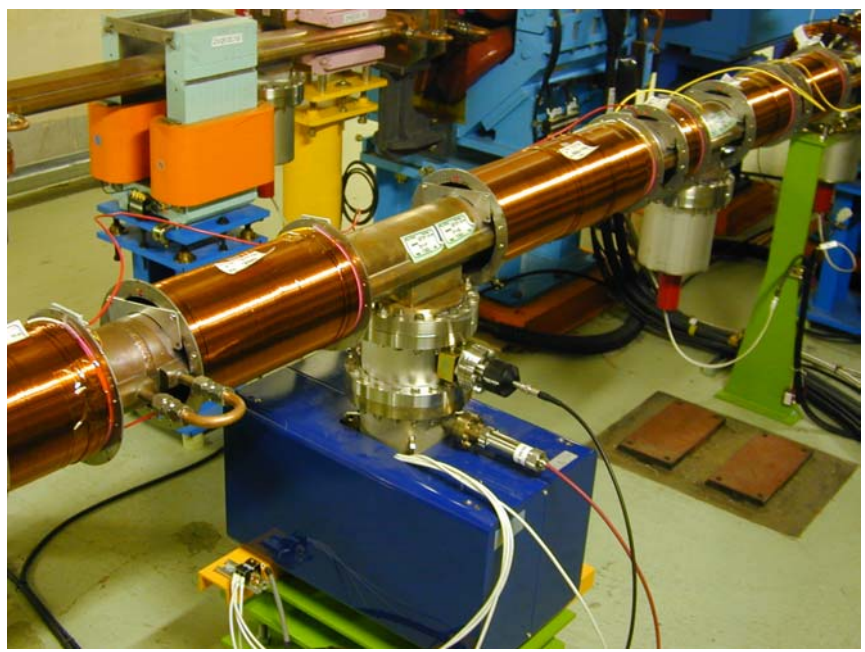


2.1 Pressure rise due to electrons_10

- Beam size blow up ➡ deteriorates luminosity
- As a counter measure, solenoids has been winded almost whole positron ring to suppress ECI (at present, 2.3 km out of 3 km)

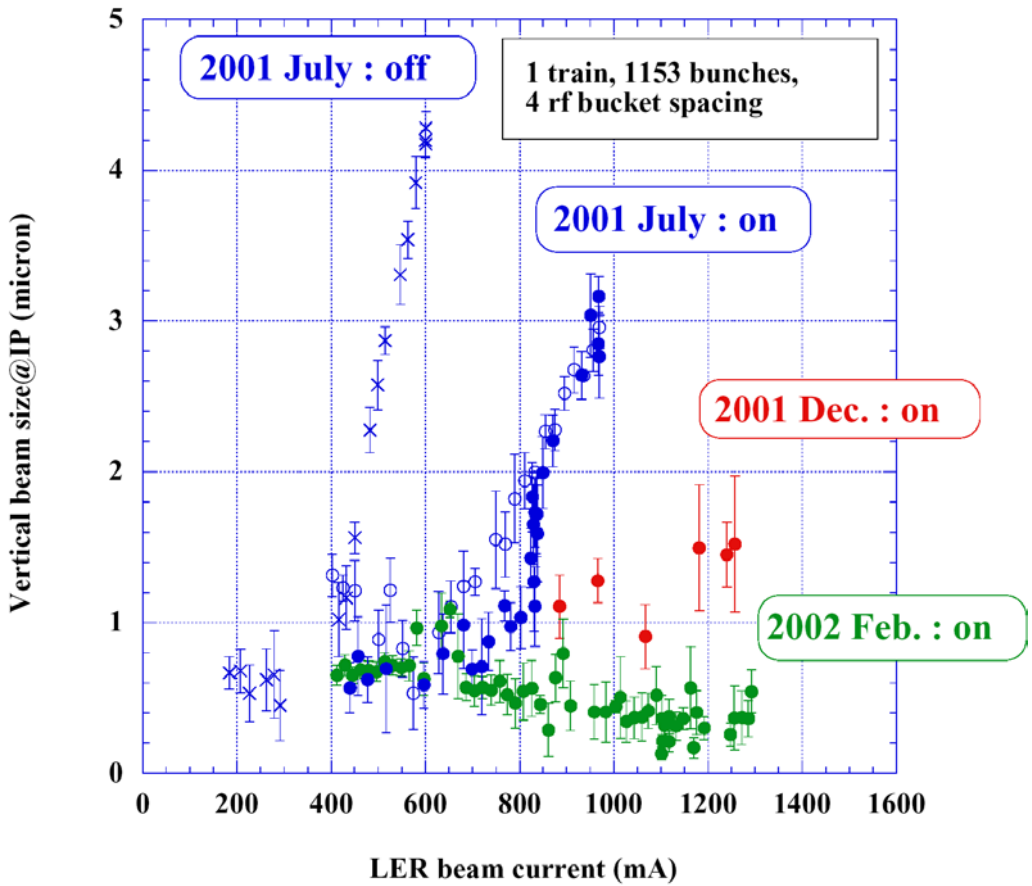
Max. 50 G





2.1 Pressure rise due to electrons_11

- Effect of solenoid:
- Non-linear pressure rise was also almost disappeared at the same time.
- Remained at several parts (aluminum chamber, etc)
- How about for higher current?

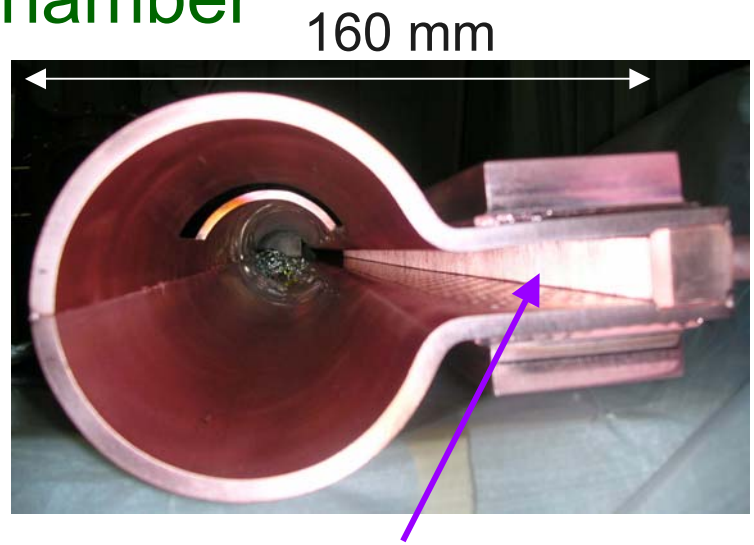


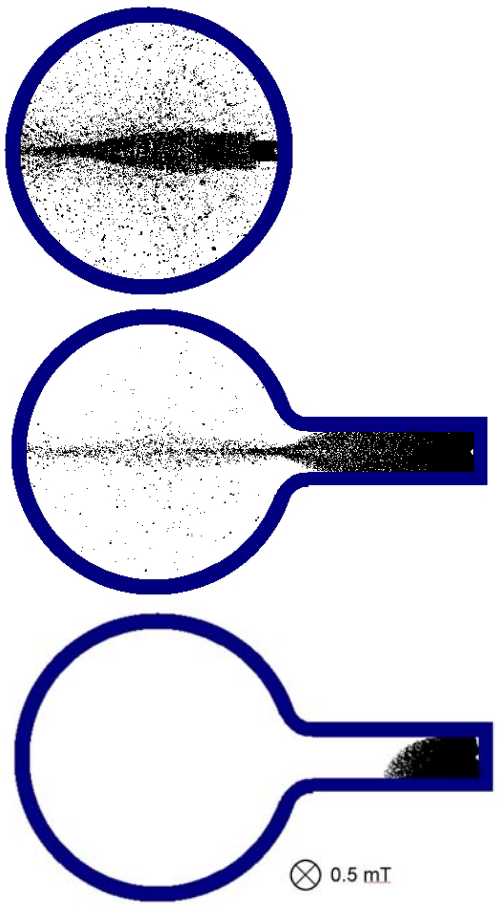
By courtesy of H.Fukuma

➡ Solenoid windings will be still continued (add to no or week field region)

2.1 Pressure rise due to electrons_12

- Countermeasures for future
  - Ante-Chamber

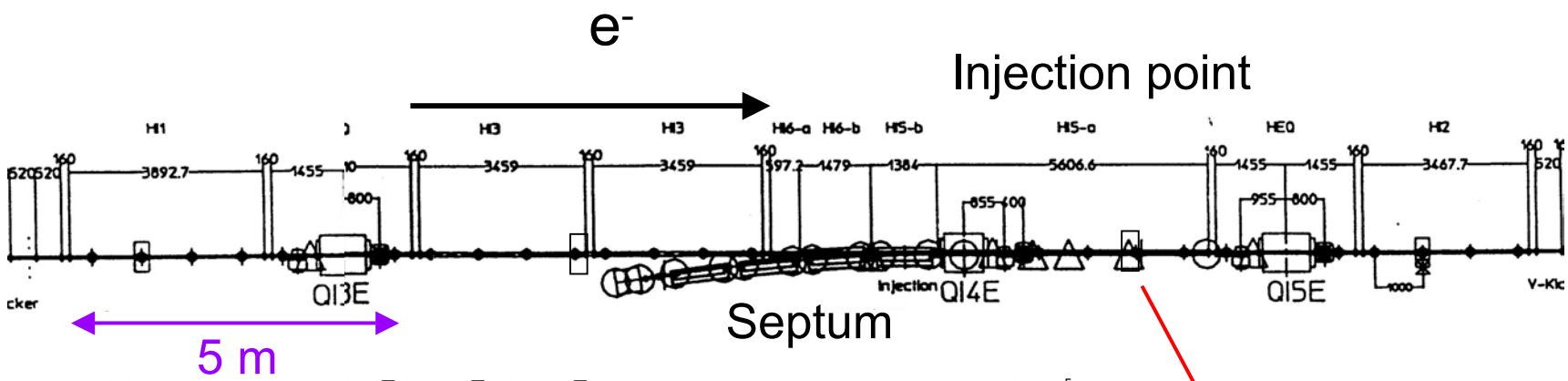


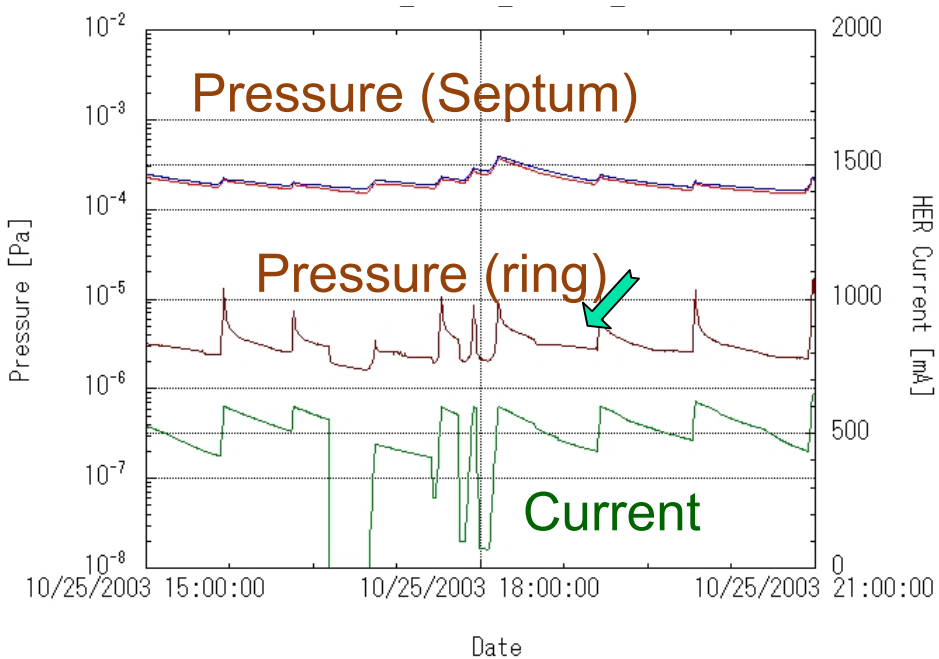


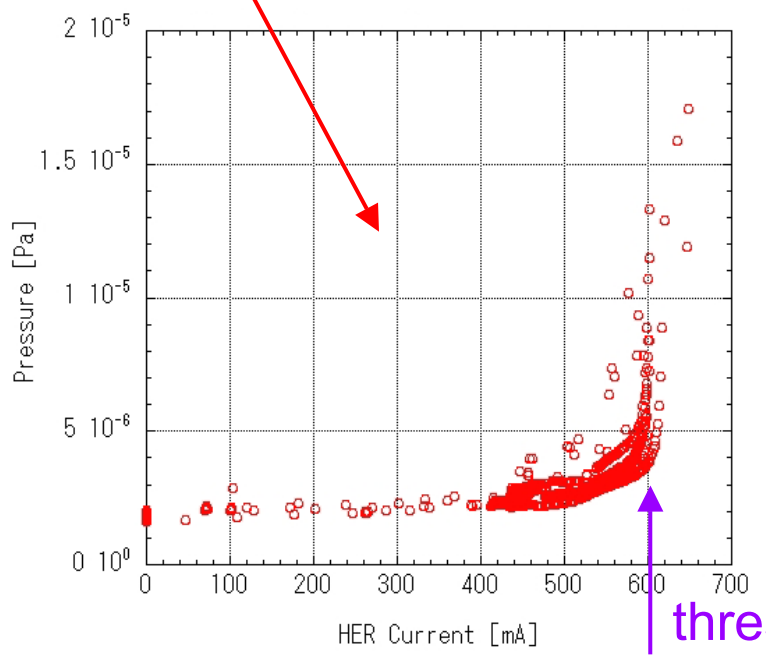
  - Solenoid
    - Inside of Q?
  - Coating to reduce secondary electron yield
    - TiN, NEG, • • •

2.2 Pressure rise at injection point_1

- Pressure rise at beam injection point during injection

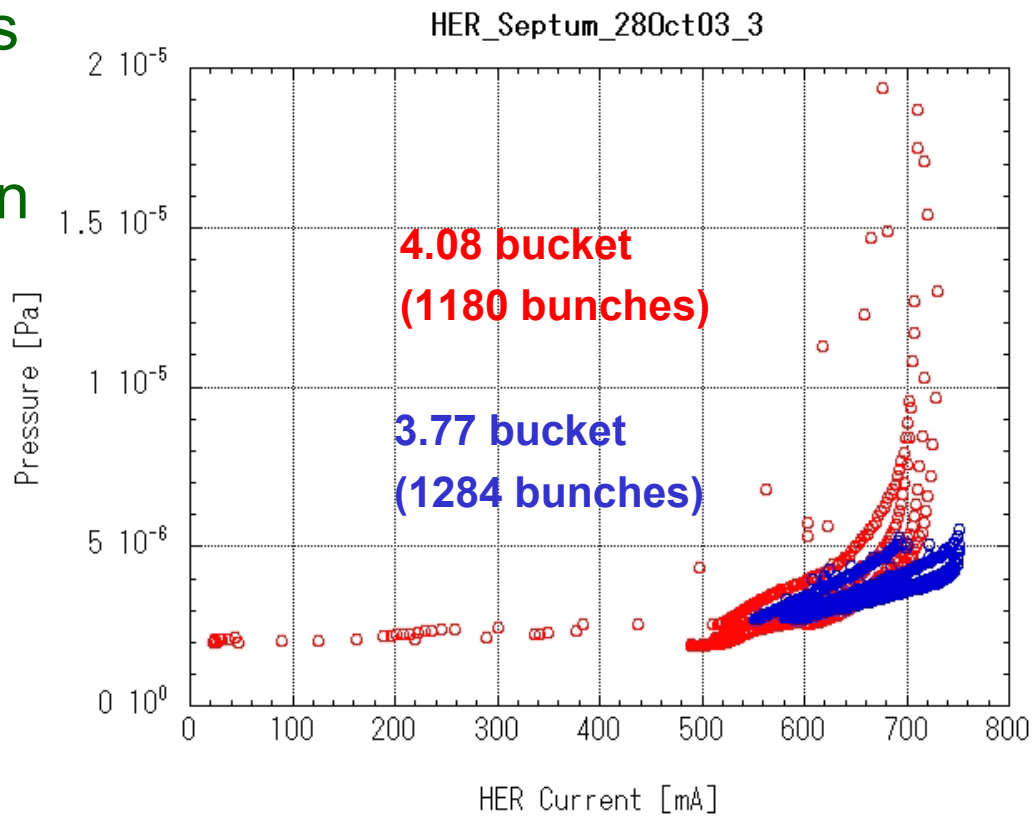






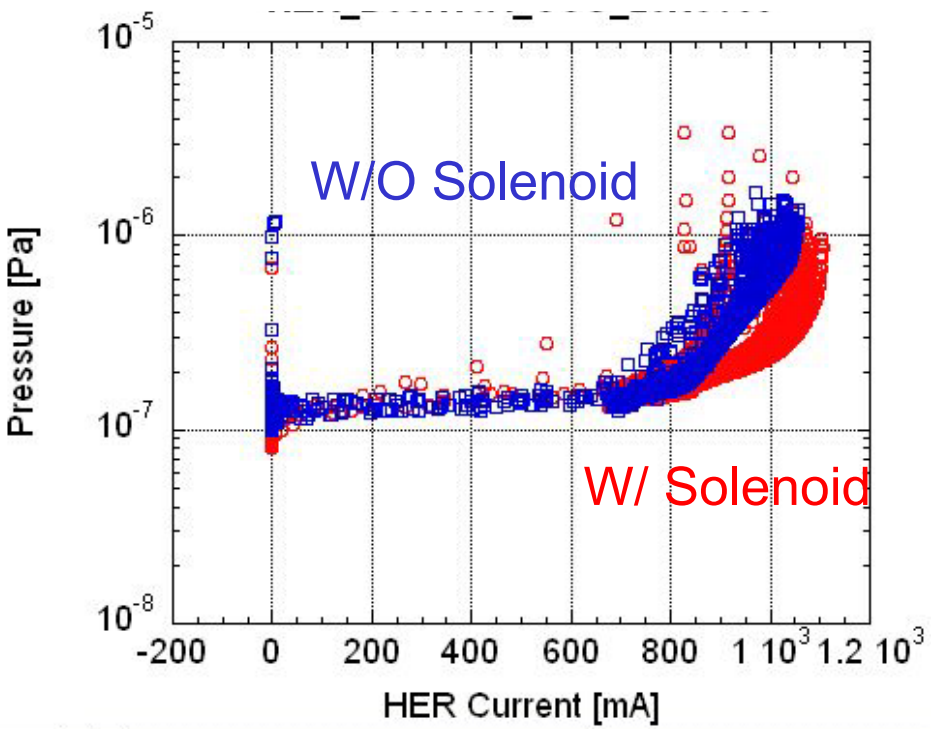
2.2 Pressure rise at injection point_2

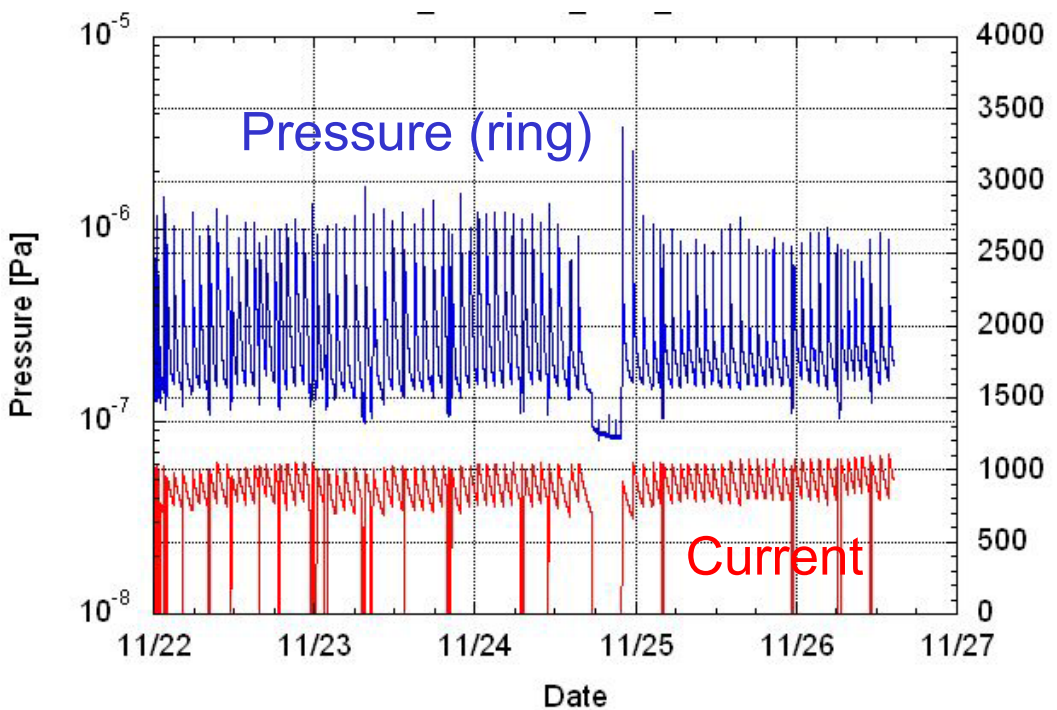
- Characteristics
  - Observed at injection points of both rings (e^- and e^+)
  - Depend on bunch fill pattern (threshold moves)
  - The pressure increases rapidly at some beam current.
  - Only during beam injection (Kickers are on)
  - Induces vertical beam oscillation



2.2 Pressure rise at injection point_3

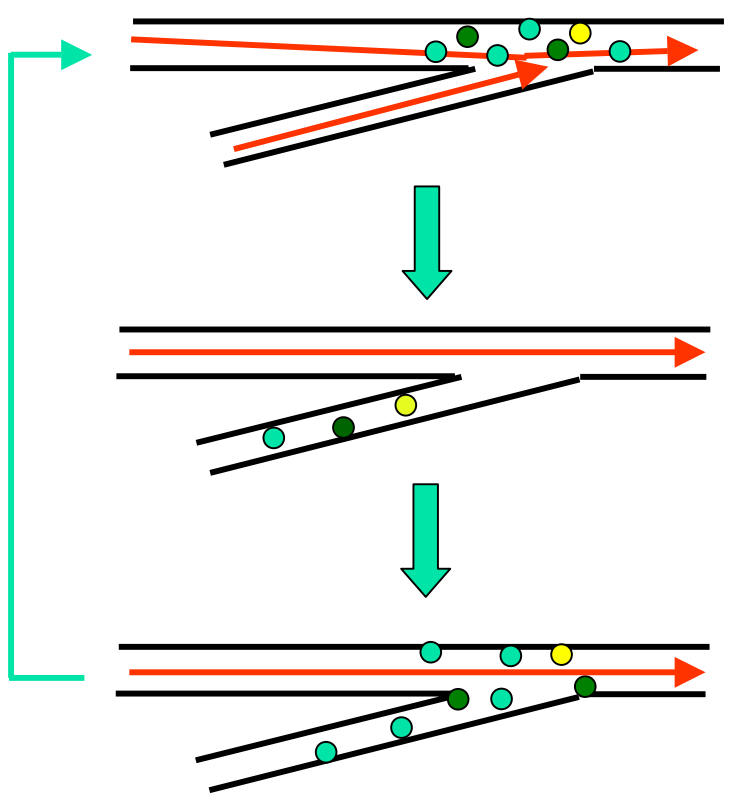
- Characteristics
  - Threshold changes by external solenoid fieled (~40 G)
  - Pressure rise is larger when the injection interval is longer and the pressure in septum chambers are high.





2.2 Pressure rise at Injection point_4

- One possible model



- During injection, the multipactoring of electrons occurred at a beam current and adsorbed gas is desorbed.
- After injection, the multipactoring stop and then the desorption ceases as well.
- During operation, the molecules from septums adsorbed on the inner wall of beam duct.

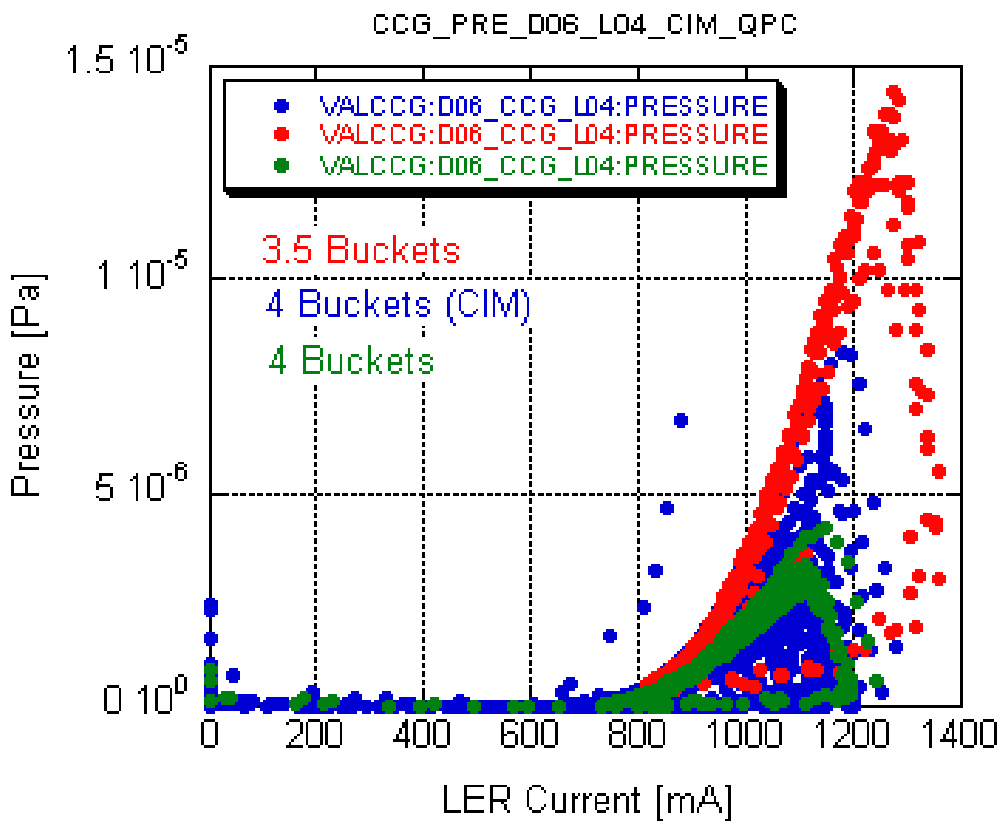
2.2 Pressure rise at Injection point_5

- Questions
  - Why only during injection?
    - Different beam orbit? Injection beam?
  - Multipactoring in electron ring?
- Temporal countermeasure
  - Baking of septum
    - Effective to reduce height of pressure rise
    - Not perfect
  - External magnetic field (Solenoid)
    - Not enough now
- Further studies are necessary

2.3 Pressure rise due to heating by HOM_1

- Abnormal pressure rise region was observed at the beam current higher than ~800 mA (LER).

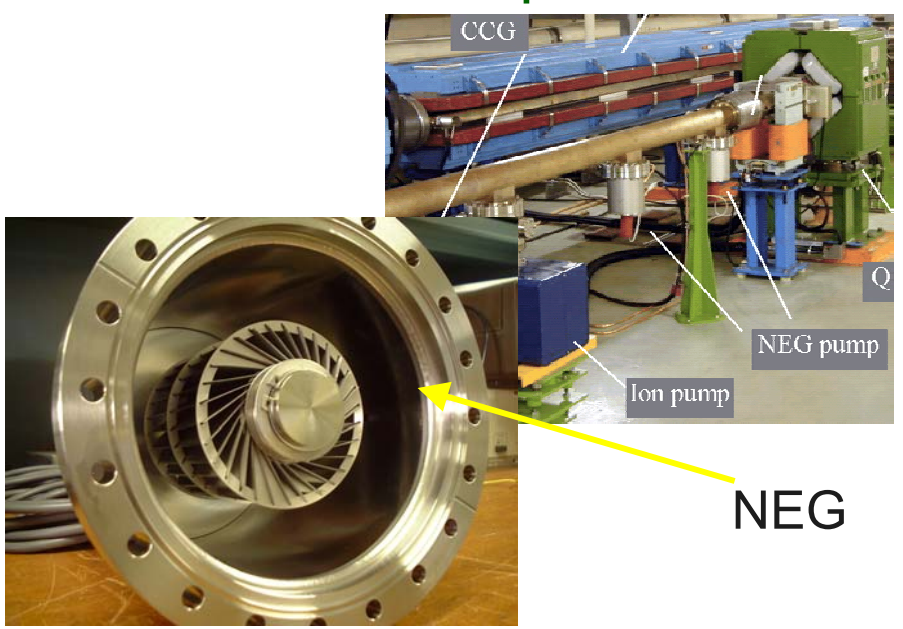
- Characteristics
  - Pressure rises rapidly against the current.
  - But it has a hysteresis behavior (heating)
  - Insensitive to bunch fill pattern
  - Vacuum scrubbing proceeds slowly



2.3 Pressure rise due to heating by HOM_2

- Characteristics
  - Only near special vacuum components, i.e. movable masks (collimators) → big HOM sources (several kW)
  - Temperature of NEG chamber near mask is higher than other ones.(estimated temperature > 150 °C)
  - Pressure distribution is almost same as the temperature's
  - Desorbed gas is H_2

Gas desorption from NEG heated by HOM generated at movable mask.

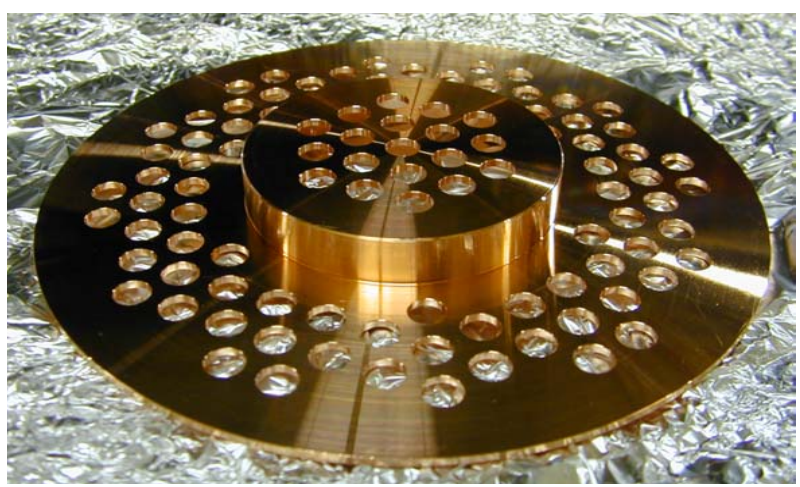


2.3 Pressure rise due to heating by HOM_3

- Countermeasure_1
  - HOM generated at movable mask intrude inside the NEG chamber through slits at port
  - RF shield gaskets with many holes of ϕ 6~8 mm is added between beam duct and NEG chamber.
  - It works partially but it was not perfect (farther NEG began heating!).

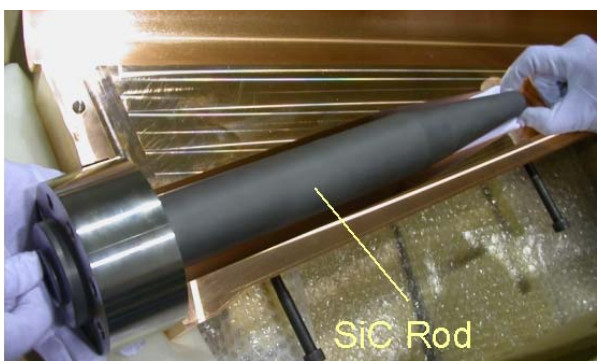
Slit at beam chamber (LER)

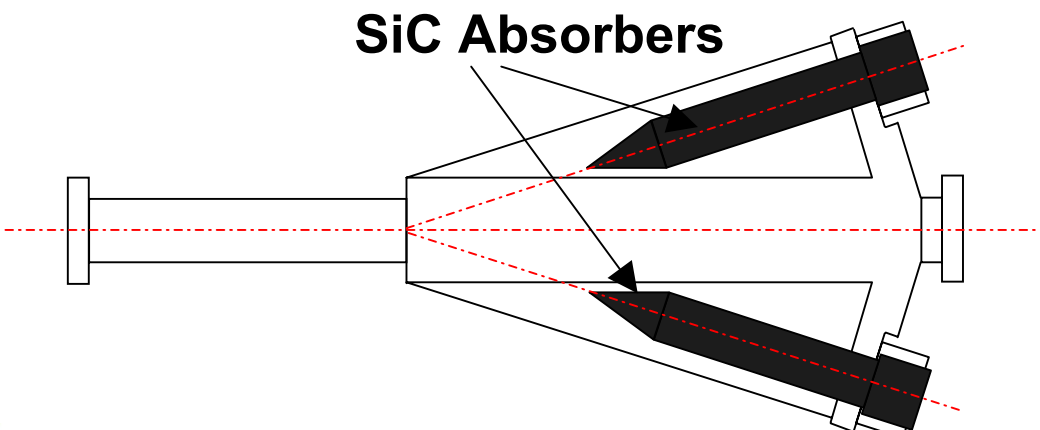
RF shield gasket



2.3 Pressure rise due to heating by HOM_4

- Countermeasure_2
  - HOM dampers were installed near movable masks
  - HOM damper is specialized to damp TE11 mode like HOM

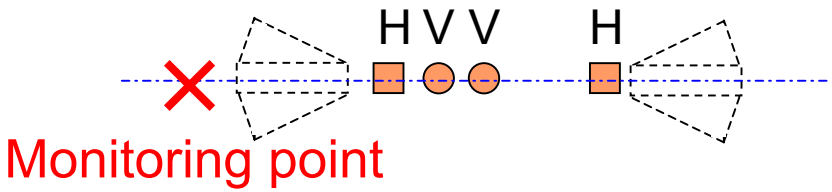


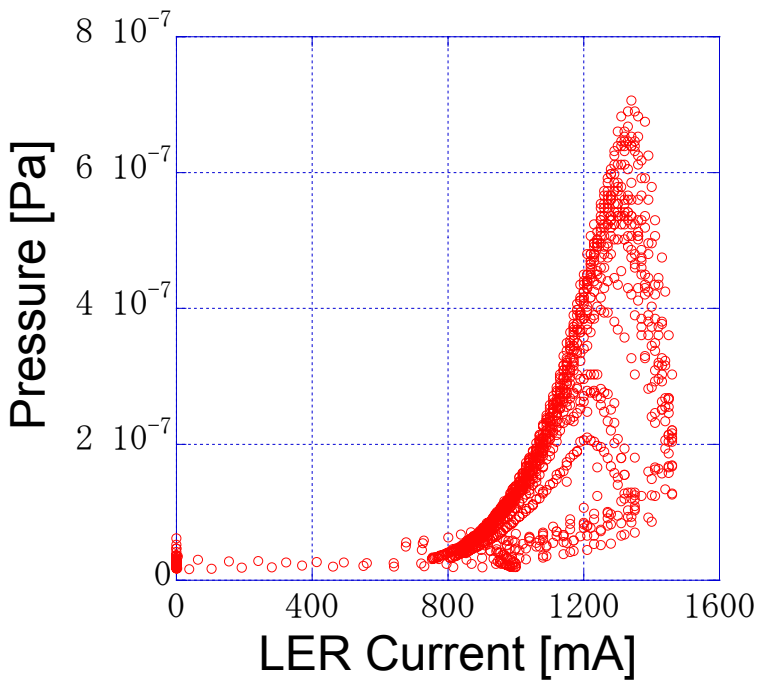


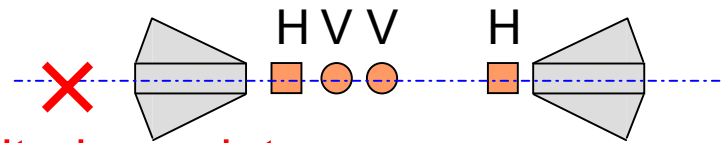
View from beam side

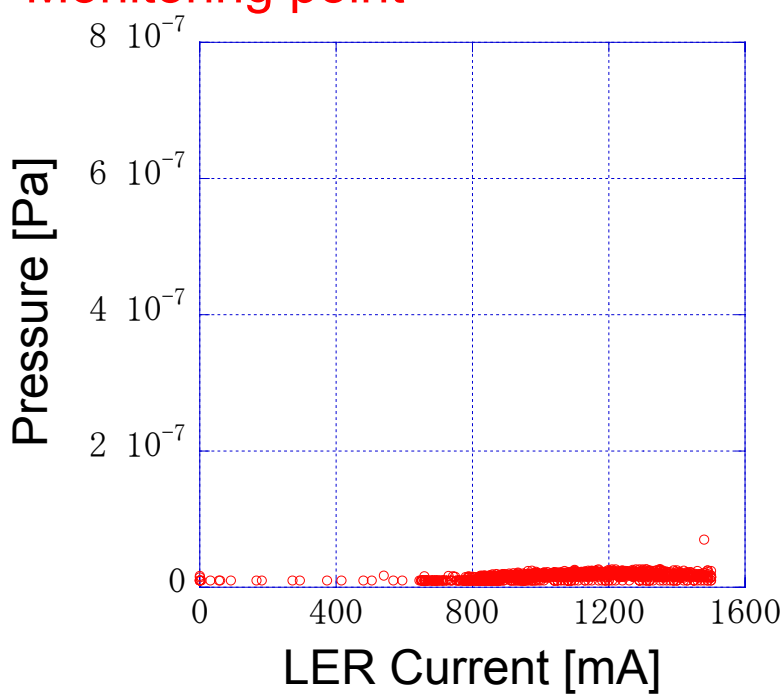
2.3 Pressure rise due to heating by HOM_5

- Effect of HOM damper ➡ Quite well









3. Summary

- Several abnormal pressure rises have been observed in KKEB
  - Due to electrons (in positron ring)
    -> Solenoid is effective. But enough in future?
  - Due to injection beam ? (electron and positron rings)
    -> Have to be understood. Electron multipactoring?
  - Due to heating by HOM (positron ring)
    -> Deliberate design of vacuum components are necessary to reduce and absorb HOM
- Further investigations on pressure rises are required for further higher intensity rings
  - Surface treatment (coating), Structure of beam chamber, Detailed simulation on ECI and multipactoring, …..